

**APPLICATION**

**FOR**

**UNITED STATES LETTERS PATENT**

**TITLE:**        **LOW DIELECTRIC CONSTANT  
CARBON FILMS**

**INVENTORS:**   **Kramadhati V. Ravi and  
Michael C. Garner**

Express Mail No. EL 990 136 128 US

Date: March 25, 2004

LOW DIELECTRIC CONSTANT CARBON FILMS

Background

This invention relates generally to the formation of low dielectric constant carbon films for semiconductor integrated circuit fabrication.

5       As device dimensions have shrunk and the speed of logic in microprocessor products has increased, a limit is being faced because of the RC time constant associated with interconnects and their related dielectrics. There is now a need to develop new interlayer dielectric materials with  
10       decreasing dielectric constants below that of traditional silicon dioxide dielectric material (about 4).

      Currently, common interlayer dielectric materials have a low mechanical strength as a result of using doped oxides. One example is carbon doped oxide. Alternatively,  
15       common dielectrics may be made of organic materials such as spin-on dielectric. The poor mechanical strength of these existing dielectric materials leads to mechanical and structural problems during wafer processing and assembly operations.

20       Consequently, there is a need for alternative low dielectric constant materials which exhibit good mechanical strength.

### Brief Description of the Drawings

Figure 1 is an enlarged, partial cross-sectional view through one embodiment of the present invention at an early stage of manufacture;

5        Figure 2 is an enlarged, partial cross-sectional view of one embodiment of the present invention at a subsequent stage of manufacture;

Figure 3 is an enlarged, partial cross-sectional view at a subsequent stage of manufacture in accordance with one  
10        embodiment of the present invention;

Figure 4 is an enlarged, partial cross-sectional view at a subsequent stage of manufacture in accordance with one embodiment of the present invention; and

Figure 5 is an enlarged, cross-sectional view at still  
15        a subsequent stage of manufacture in accordance with one embodiment of the present invention.

### Detailed Description

Referring to Figure 1, a semiconductor substrate 10 may be covered with a diamond-like carbon film 12. The  
20        diamond-like carbon film 12 may be formed of a mixture of significant as opposed to trace amounts of both diamond and non-diamond forms of carbon. One example of a non-diamond form of carbon may be graphite.

In one embodiment, the diamond form of carbon may be  
25        characterized by a particular type of bonding between carbon atoms. The diamond bonds are  $Sp^3$  hybridized, which

means the bonds are very strong, which gives diamond its unique properties (very high hardness, modulus, thermal conductivity, etc.).

5 The diamond material in the film 12 may be deposited using plasma enhanced chemical vapor deposition (CVD) processes using mixtures of a hydrocarbon such as methane and a super saturation of hydrogen. If the ratio of methane to hydrogen is small, e.g., 1 to 3 percent methane and 97 to 99 percent hydrogen, the diamond material may be  
10 predominantly composed of  $Sp^3$  bonded carbon, i.e., pure diamond films. As the methane concentration, relative to hydrogen is increased, the films become mixed phase films with both diamond bonded ( $Sp^3$ ) carbon and non-diamond bonded ( $Sp^2$ ) carbon, which is often graphite.

15 The non-diamond form of carbon in the film 12 is made up of carbon whose inter atomic bonds are not  $Sp^3$  bonds. Typically, the non-carbon material may be graphite  $Sp^2$ , amorphous carbon, defects, and the like.

The ratio of diamond-to-non-diamond materials in the  
20 film 12 can vary quite widely depending upon the process conditions. For the case of low dielectric constant, high mechanical strength films, in one embodiment 10 to 20 percent methane in hydrogen may be used. The synthesis (deposition) process is such that a high methane to  
25 hydrogen ratio is used and a mix of diamond and non-diamond

forms of carbon, mixed randomly in the film 12, is the result.

The film 12 may be prepared using plasma enhanced CVD processes using a mixture of a hydrocarbon, such as methane and hydrogen, as the process gas mix. Several CVD techniques can be used to deposit the films including microwave assisted CVD, filament assisted CVD, and direct current (DC) glow discharges. Typically, the methane and hydrogen are cracked by the plasma processes and the byproducts of the cracking process (atomic hydrogen, methyl, and other radicals) appropriately react on the surface of the wafer to result in the formation of diamond material. As described above, the phase purity ( $Sp^3$  to  $Sp^2$  ratio) of the films can be modulated by changes in the methane to hydrogen ratio.

The diamond-like carbon film 12 may be covered with a photolithographically processed hard mask 14 which has openings positioned at desired points along the hard mask 14. The structure covered by the patterned hard mask 14 is then exposed to an oxygen plasma indicated by the letter I. A reactive ion etching with an oxygen source may be undertaken with substrate bias to increase vertical etching and to reduce lateral etching and undercutting.

As shown in Figure 3, the etched film structure may be exposed to oxygen plasma indicated at F. In one embodiment, the oxygen plasma may be without substrate bias

to etch the sides of the diamond-like carbon film 12 exposed by the reactive ion etching shown in Figure 2. The exposure to the oxygen plasma creates porosity within the film 12. In one embodiment, the oxygen plasma exposure may  
5 be at a pressure of 1 to 20 Torr, at a temperature of 300 to 400C, and a power of about 1 kilowatt.

In one embodiment, the gasification proceeds from the side of the layer 12. The side attack may reduce dimensional changes to the film 12, compared to etching  
10 from all directions. However, the hard mask 14 may also be removed before gasification in some embodiments.

The process conditions may selectively etch and gasify the non-diamond forms of carbon in the film 12 with minimal attack of the diamond bonded material in one embodiment.  
15 The resulting porosity in the patterned carbon film 12 reduces the dielectric constant of the film 12. In one embodiment, the dielectric constant may be below 2 with a porosity of about 50 percent.

The hard mask 14 may be removed as shown in Figure 4.  
20 Then, as shown in Figure 5, the copper layer 16 may be plated over the resulting structure to form a damascene structure. The copper layer 16 forms the next level metal layer in a damascene structure. In some embodiments, a barrier layer may be provided between the copper layer 16  
25 and the modified diamond-like carbon film 12a.

Some embodiments of the present invention may exhibit relatively high mechanical strength because of the presence of diamond in the carbon film material. In addition, because of the porosity, the dielectric constant may be  
5 reduced because of the presence of micro voids and other internal discontinuities in the film. Thus, the dielectric patterning process may provide desirable dielectric capacitance which has a relatively large effect with closely spaced lines. In some embodiments, greater  
10 circuits speeds may result.

In one embodiment, the mixed phased diamond films may be synthesized using a process of deposition, etching by atomic hydrogen, and deposition. In some embodiments, the modulus of the resulting film may be greater than 250 GPa.

15 While the present invention has been described with respect to a limited number of embodiments, those skilled in the art will appreciate numerous modifications and variations therefrom. It is intended that the appended claims cover all such modifications and variations as fall  
20 within the true spirit and scope of this present invention.

What is claimed is: